REGRESSION MODELLING OF SERVICE LIFE PREDICTION OF EXTERNAL WALL PAINTING OF ALGIERS BUILDING

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Abstract: *Paint coatings, as a protective layer of external wall building envelopes, are mainly exposed to several degradation agents, including environmental and climate factors. In the case of North African countries, there are no studies about the estimation of the performance of this coating exposed under the conditions of these regions during its service life. For this purpose, this paper presents a statistical study on the evolution of service life (SL) prediction for external wall painting, based on the inspection of the degradation state of 45 building facades located in Algiers, Algeria. The selection of different investigated external wall paintings is mainly focused on considering their age, the distance from the coastal zone, and the facade orientations. The degradation severity of selected coatings was also estimated in this work using the calculation of a numerical index (Sw). Simple regression analysis (graphical method) and multiple linear regression analysis (MLR) are used for the development of a mathematical model. The main results of this work indicate clearly a high correlation between the values predicted by the mathematical model, which corresponds to a high value of coefficient of determination of 0.95. A comparison study is also conducted in this investigation work between the performance of the obtained model and the MLR model developed by previous research about the SL prediction of paint coating. As a result, the obtained model during this study gives good precision despite the moderate quantity of considered external wall painting.*
Keywords: *External facades painting, Degradation severity, Degradation agents, Service life prediction.*

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Introduction

Nowadays, the good quality and the sustainability of building materials are very important for the good stability of social and economic conditions of modern cities. The concept of sustainability translates to the ability of building elements to present during their SL a high performance in a specific environmental condition, without any repair and renovation process on their surfaces. In reality, the durability characteristic is not limited specifically to a fundamental quality of a building material; simple improvement in material properties could impact better protection of its resistance to the different agents of degradation, which leads to an increase in its SL. Although the materials used in the construction field have become more durable, the aging process of these elements is inevitable. This factor can adversely affect the initial characteristics and performances of each construction element [1]. This loss of performance occurring at an early age is certainly not in agreement with the requirements for sustainable construction materials. Thus, various degradations occur during the SL of these construction elements, and their intensities are generally related to the different environmental and climatic factors. In this context, the role of the coating applied to the external facade wall of the building is defined as a protective layer resistant to these various degradation factors.

Among the most common coatings used for the external wall of building envelopes, the paint coating attracts considerable attention due to its different characteristics, which offer several advantages compared to other coating materials [2]. Despite these advantages, it is generally admitted that the paint surfaces will not achieve the required performance during their SL, which is usually related to several origin effects that can control their service life, like the environmental and climate conditions, the maintenance and reparation defects, etc. [3,4]. Moreover, a good precision for developing different methodologies for the estimation of the service life (ESL) of applied coating is generally correlated to the consideration of these factors. The prediction of SL of any element construction aims to evaluate its performance over time and to predict the required maintenance necessary to repair the defects formed during its SL. Thus, there are several investigations and research studies on relationship between the degradation severity and different deterioration agents using the most recently developed statistical methods for the analysis, and the translation of the durability evolution and modeling of the degradation mechanism occurred at the paint surface [5,6]. Three categories are considered for these methods, namely: methods and durability design standards applied for the ESL, methods for the time-variant structural reliability, and maintenance optimization. According to the first methodology, the ESL can be estimated using different models like deterministic (regression analysis), stochastic, computational, and factorial methods [7]. Among these methods, the deterministic models based on the MLR analysis provide good precision for the ESL of paint coating applied to the external wall of the building [3].

Teo et al. [8] developed a quantitative model for the evaluation and optimization of effective management of maintenance costs necessary for repairing paint coatings applied to the exterior facades of buildings. Visual inspections were carried out to collect different information related to the various deteriorations that occurred during the SL of coating applied to the external facades of social buildings located in Singapore. The collected data during the fieldwork was used to develop a statistical model for different anomalies repaired to predict their appearance and propagation over time. Moreover, the shape of detected anomalies on the building element/system is determined in this work. The validation tests concluded in this study that the model obtained has good significance. On the other hand, Garrido et al. [9] proposed a procedure for the ESL based on the statistical analysis of collected information about the most degradation that occurred on the exterior facades of investigated buildings during their SL. In this work, the deterministic analysis is used to analyze and describe the degradation curves. The authors indicate in this study that this statistical method mainly needs the quantification of the different anomalies detected for the ESL of paint coatings applied on the exterior facades of old buildings. In addition, five degradation agents are considered in this work, namely, the thickness of the coating, the type of paint binder, the texture of the painted surface, substrate preparation, and solar orientation. The data was collected from 100 investigated buildings, and the peeling degradation is considered the most common coating defect. The most results obtained in this investigation work concluded that the methodology assumed gives good results for ESL of external facade painting and also supports the cost estimation for the suitable maintenance approach.

Chai et al. [10] estimated in their work the SL of paint coatings via the data collection of 220 facades located in the Lisbon region in Portugal. Based on the obtained results in this investigation, it appears that the paint coating has several characteristics that mainly affect its durability. They suggested that these factors can be organized into three groups according to their dependence on the quality of materials used, the quality of workmanship, and the environmental exposure conditions. Therefore, the main considered factors in this work that have an important effect on the durability of the studied coating are (i) the age of the paint coating, ii) the paint surface texture, (iii) the distance from the sea, (iv) wind and rain combined action, and (v) the facade orientations. Another study was conducted by Chai et al. [11] to develop a statistical approach for the prediction of the SL of the paint coating of the building envelope. This investigation work is based on the collection of field data via the examination of the state of degradation of 220 paint coatings that were applied to 160 buildings of different construction categories. A mathematical model was defined during this study by the application of MLR analysis, which allows the expressions of the degradation of the studied coating over time as a function of different degradation agents. The authors indicate in this work that the most degradation agents that have an important effect on the deterioration of paint coating are humidity exposure, wind and rain actions, the distance from the sea, the facades' orientations, and the paint finish. As a result of these investigations, the degradation agents indicated that 83% of different anomalies that occurred can be described by three independent variables via the model obtained by an MLR analysis with a significance threshold of 10%, classified as follows: the age of the paint coating, facade orientations, and the distance from the sea.

Silva et al. [3] proposed a procedure for the evolution of the SL of painted coating applied to the exterior facades by examining the degradation state of 220 facades of buildings located in the Lisbon region, Portugal [3]. The effect of different characteristics of the studied coating and their environment on the durability of the materials is also analyzed in this work. In this case, three statistical tools were used during this work: i) simple regression analysis based on the graphical method; ii) MLR analysis; and iii) the ANN method. Mathematical models are generally used for the estimation of the deterioration level of the considered coating as well as to predict its SL. Among these three methods used in this study, it was found that the MLR analysis gives a good result for the prediction of the SL of paint coatings. Indeed, an estimation of 8.5 years ± 0.54 years.

The methodology established in this work for the ESL of external wall painting is based on the inspection of the degradation level of 45 samples located in Algiers, Algeria. In addition, a numerical index (Sw) is calculated for the estimation of the global degradation of each inspected paint coating. The effects of three degradation agents on the paint coating are considered during the inspection work, namely, the age of the paint coating, the distance from the coastal zone, and the solar orientation of the facade. The MLR analysis is used as a deterministic method for the ESL of investigated coatings applied on the exterior walls of Algiers buildings. The performance of the obtained statistical model in this work was examined by the prediction of different surface paints of external walls of buildings located in Algiers.

Materials and methods

Investigation sites

During this work, the data collection was performed from 45 external facades of residential buildings situated in 22 municipalities of Algiers, Algeria (Fig.1). In addition, three independent variables are considered

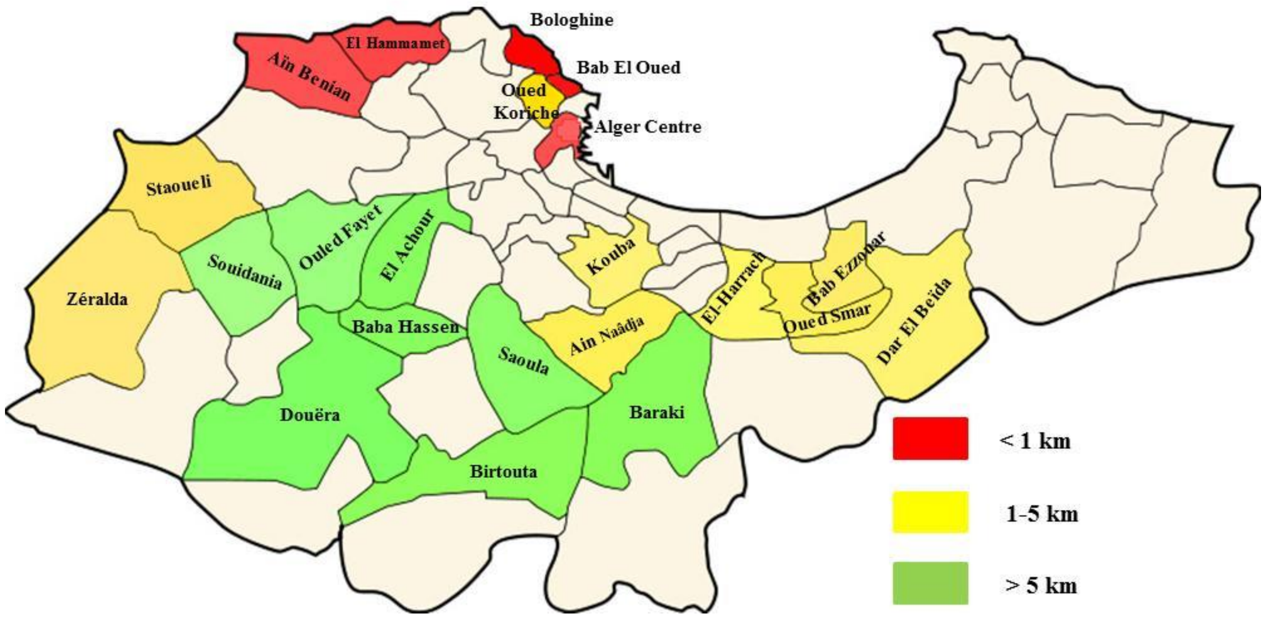

Fig. 1. *Distance from the sea of different inspected building facades*

in this investigation, namely, the age of the paint coating, the distance from the coastal zone, and the solar orientations of facades. The coating ages of inspected building facades in this study are between 3 and 42 years old, as listed in Table 1. Moreover, three categories of coated facades are studied by their distance from the coastal zone in order to evaluate andunderstand the effect of the distance from the sea

Table 1. Distribution of coating ages of different inspected surface paints

Ages of paint coatings (years)	Investigated samples (%)
Under 10	35.56
Between 11 and 20	35.56
Above 21	28.88

on the degradation severity of studied coatings. Practically, for this parameter, the distances are gathered into three categories for the external facades of buildings located: (a) > 5 km; (b) 1-5 km; and (c) < 1 km. The Google Maps application is used in this study for the identification of the orientation of the different facades by considering eight orientations of the facade building: West (W), South (S), East (E), North (N), North/West (N/W), South/West (S/W), South/East (S/E), and North/East (N/E) (Table 2).

For the assessment of the performance of the statistical model derived in this study, six (06) painted surfaces of residential buildings were inspected in Algiers (Table 3). The sampling was carried out by taking into account the three parameters, namely, the coating age, the distance from the coastal zone, and the solar orientations of the facade.

Table 2. Facade orientations versus the number of investigated samples

Facade orientations	Investigated facades (%)
N	13.33
E	8.89
W	24.44
S	24.44
N/E	8.89
S/E	8.89
S/W	6.66
N/W	4.44

Table 3. General information about the investigated samples

Investigated sites		Distance from the sea			
Site localizations	Abbreviations	Real distance from the sea (km)	Categories	Coating age	Facade Orientation
Cité Rue Amar Hamiti-Hussein Dey	CRAH	0.64	< 1 km	≈ 1980	S/E
Cité fico 241 logts-El Magharia	CFEM	1.28	1-5 km	2018	S/E
Cité 118 logts-El Magharia	CLEM	1.36		2018	E
700 logts-Bentalha-Baraki	LBB 1	11.51	> 5 km	2013	W
700 logts-Bentalha-Baraki	LBB 2	11.51		2013	N
700 logts-Bentalha-Baraki	LBB 3	11.47		2013	E

The field work description

Different methods and tools are used for the collection of data during the fieldwork, the methodology is described as follows: (i) taking photos of different targeted facades; (ii) measuring of facade dimensions; (iii) collecting from local administration (OPGI, Office de Promotion et de Gestion Immobilière) different information about the first and the last retrofitting operation; (iv) on-site identification and analysis of applied painting facades; and finally (v) completing of inspection form established for each inspected facade. The independent variable of "age coating" is defined as the time separating the date of the last painting with total or partial reparation of the paint coating and the inspection date. Based on the OPGI's technical documents, the acrylic paint coating is applied to all inspected facades. On the other hand, the effect of four degradation agents on the degradation severity of paint surfaces is studied during this work, i.e., color change (CC), chalking (CG), cracking (CK), and loss of adherence (LA). Thus, the estimation of the degradation level of each considered anomaly is established according to its corresponding international standards (Table 4).

Table 4. Studied anomalies with corresponding international standards

Anomalies	Standards	
CC	ISO 3668[1] and ISO 4628-1[2]	
CG	ISO 4628-6[3] and ISO 4628-7[4]	
CK	ISO 4628-4[5]	
LA	Blistering	ISO 4628-2[6]
	Peeling	ISO 4628-5[7]

Degradation severity

A mathematical expression is generally applied to explain the overall degradation observed at different inspected paint surfaces by using the different information and data collected during the fieldwork. A group of authors established a numerical index for the quantification of the global deteriorations that occurred during the SL of building materials [12,13]. This numerical index (Sw), which translates the degradation severity, is described in (1).

$$S_w = \frac{\sum(A_n \cdot k_n \cdot k_{a,n})}{At \cdot k} \cdot 100\,, \tag{1}$$

where *Sw* represents the degradation severity of analyzed materials (%); k_n is the multiplying factor of defects n, $k_n = \{0, 1, 2, 3, 4\}$; $k_{a,n}$ is the weighting coefficient explaining the relative weight of each considered degradation ($k_{a,n} \in R^+$); $k_{a,n} = 1$ by default; A_n is the area of paint surfaces affected by the degradation n (m^2); A is the global facade area, (m^2) and k represents the multiplying factor translating the maximum deterioration level of the studied coating with area A. In this work, the evolution of the multiplying factor (k) indicates the degradation levels on the SL of the considered materials. As a result, five degradation levels noted: A, B, C, D, and E are considered in this work for k values.

The different anomalies detected on the inspected painted surfaces do not all have the same relative importance on the overall degradation of this coating. For this purpose, the analysis of the relationship between the anomalies, their causes, and the consequences on the performance of the system becomes fundamental to evaluate the influence of the stages of production on the appearance of the anomalies and on the performance of the paint coating systems. Based on the study performed by Bauer et al. [6], the relative importance (weighting factor) of each anomaly detected in the coating surface can be translated by the calculation of a coefficient obtained through correlation matrices. These matrices are scored with values of 0 (no relationship),

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[1] ISO 3668, Paints and varnishes — Visual comparison of the colour of paints, Draft International Standard, 44 (2017).

[2] ISO/DIS 4628-1, Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance —Part 1: General introduction and designation system, Draft International Standard, 44 (2016).

[3] ISO 4628-6, Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 6: Assessment of degree of chalking by tape method, BSI Standards Publication, (2011).

[4] ISO 4628-7, Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 7: Assessment of degree of chalking by velvet method, 2016.

[5] ISO 4628-4, Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 4: Assessment of degree of cracking, Draft International Standard, 44 (2016).

[6] ISO 4628-2, Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 2: Assessment of degree of blistering, Draft International Standard, 44 (2016).

[7] ISO/DIS 4628-5, Paints and varnishes — Evaluation of degradation of coatings — Designation of quantity and size of defects, and of intensity of uniform changes in appearance — Part 5: Assessment of degree of flaking, Draft International Standard, 44 (2016).

1 (low relationship), or 2 (strong relationship). As a result, the weighting coefficient ($k_{a,n}$) can be calculated by the ratio of the product between the cause indicator and the performance indicator and the normalization of the maximum value of the product between the performance indicator and the cause indicator, according to (2).

$$k_{a,n} = \frac{I_c \cdot I_p}{max(I_c \cdot I_p)}, \tag{2}$$

where $k_{a,n}$ is the weighting coefficient; I_c is the importance index related to the causes of each anomaly; I_p is the relative importance index of each anomaly in the facade of loss performance. More details about these two indicators are given in the following paragraphs.

In this work, different causes or effects on the service life of painted surfaces are classified into four main groups namely, Materials' characteristics, Design factors, Environmental and exposure conditions, and Maintenance. This classification is established based on the study of Chai. et al. [11].

The importance of the relation between cause and pathology is evaluated using indices to designate a possible correlation. The value of the correlation index is as follows: 2 for a strong relation, 1 for a possible relation, and 0 when there is no relation between the causes and pathologies. The relevance of each pathology is measured by an importance index related to the causes (*Ic*), described by (3). This index evaluates the importance of the causes of several studied pathologies.

$$I_C = \frac{\sum_{i=1}^{N} \mu_{ci}}{\mu_{c\,tot}} \quad , \tag{3}$$

where I_c is the importance index related to the causes of a pathology, N is the number of groups analyzed (Materials' characteristics, Design factors, Environmental and exposure conditions, and Maintenance; in this case N = 4), μ_{ci} is the mean of the correlation indices for the causes of a pathology in each group analyzed, and μ_{ctot} is the sum of all μ_{ci} values for all anomalies (color change, chalking, cracking, and loss of adherence).

For the determination of the performance loss index (I_p), the correlation of the anomalies with the loss of performance of the building facade is analyzed. The anomalies are then classified based on their influence on the performance decrease into three groups: structural, watertightness, and aesthetics, where the same correlation indices are chosen (2 for a strong relation, 1 for a possible relation, and 0 when there is no relation). For each anomaly, the sum of the correlation indices in the three performance groups is made. Through this method, it can be compared how much each anomaly affects the performance loss. The relative importance index of different studied anomalies in the facade loss of performance (*Ip*) is calculated by (4).

$$I_p = \frac{P_{ki}}{P_{k\,total}}, \tag{4}$$

where *Ip* is the relative importance index of an anomaly i in facade loss of performance, N is the number of anomalies (in this case N = 8), P_{ki} is the index of loss of performance of an anomaly *I* (sum of the correlation indices for each pathology), $P_{k\,total}$ is the sum of the values of p_{ki}, considering all considered anomalies detected in painted surfaces.

MLR analysis

To investigate the relationship among the different factors and the dependent variable, the MLR analysis is one of the most statistical methods that is usually applied in this field. Indeed, for any application of MLR in ESL, the main objective is generally to explain a specific reality and try to predict the variation of dependent variable values (Sw) versus the independent variables. Equation 5 gives the general mathematical formula used in MLR analysis.

$$Y_i = b_0 + b_1X_1 + b_2X_2 + \cdots + b_iX_i + \varepsilon_i = \sum_{i=1}^{p} = b_iX_i + \varepsilon_i \ , \quad (5)$$

where Y represents the dependent variable, Xi values are the independent variables, bi values are the coefficient parameters of the obtained model, and ε_i is the model's random error. The MLR analysis is performed with SPSS software and Microsoft Excel during this work.

Results and Discussion

Quantification of degradation factors

The estimation of the service life of each building material using the MLR analysis generally requires the quantification of the considered qualitative factors by the graphical method. According to this method, both simple linear and nonlinear regression models can be established depending on the considered factors that strongly affect the sustainability of paint coatings. Thus, three characteristics are considered during this work: the coating age, distance from the sea, and facade orientations. The relationship between Sw and the age of the different inspected paint coatings can be translated by different regression analyses of linear, quadratic, cubic, exponential, and logarithmic methods. Therefore, this approach was applied in this work for the estimation of the reference service life (RSL) of inspected external wall painting (45 samples) after the quantification of two independent variables, the distance from the sea and the facade orientation. It consists of adjusting a simple linear regression line with a dispersion of different points plotted in two dimensions; the X axis indicates the variation of the "age variable", and the Y axis corresponds to the values of the severity of degradation index (Sw). The coefficient of determination (R^2) indicates the percentage of variance of the dependent variable of Sw. The mathematical model was obtained using a graphical method based on simple linear regression analysis of the relationship between the values of the Sw and the inspected paint coating ages.

Before the estimation of the RSL and the quantification of the qualitative independent variables, the degradation level must be defined for each type of anomaly according to its characteristics. However, there are different possible degradation defects on the paint surface, due to the combination effect occurring between various degradation agents and mechanisms. In general, the deterioration level is mainly explained by the distribution degree of the anomaly on the facade coating. For this purpose, various investigations were carried out in order to implement a classification system of different anomalies detected in the paint surface to express the physical and performance loss of the building facade [14-16]. Based on these studies, the authors define five levels, which clearly explain the severity of paint degradations, from 0 to 4, where 0 corresponds to no significant degradation and 4 to strong degradation. As indicated in Table 5, the degradation levels are regrouped depending on the severity values. Level 3 is defined as the limit SL of the painted surface, which corresponds to the Sw values ≥ 20%.

The RSL of investigated paint surfaces is obtained using a simple regression analysis, in which a trendline is adjusted to the scatter plot established for Sw values and the age of the coating, Y and X axes, respectively (Fig.2). Indeed, two trendlines were applied, namely linear and second-degree polynomial regressions, which are adjusted to the scatter plot obtained via data collected during the fieldwork. The respective equations and the coefficient of determination obtained by the two models are also presented in this Figure. The linear and nonlinear (polynomial) models show values of R^2 equal to -0.473 and 0.304, respectively. These values highlight that the tendency of degradation severity results as a function of coating age can be explained by a second-degree polynomial curve.

Table 5. Relationship between severity values and degradation levels [4]

Severity index	Degradation levels
$S_w < 1$ %	0
1% $< S_w <$ 10 %	1
10 % $< S_w <$ 20 %	2
20 % $< S_w <$ 40 %	3
$S_w >$ 40 %	4

Indeed, 30.44% of the degradation severity can be explained by this trend line by considering the age of the coating as the only explanatory variable. This result deduced from the second- degree polynomial model does not give a high precision of the degradation process of painted surfaces because the severity of degradation is not well correlated with the age of the coating system. This is probably due to the degradation process, which does not occur at the same rate over time. Thus, the degradation initially occurred at a slower rate, tending to accelerate at the end of the SL of painted surfaces; moreover, it can be due to the degradation process, which does not depend exclusively on the age of the buildings, being impacted by several reasons, as previously indicated in this study.

The RSL was also deduced from this graphical analysis. As a result, the average expected SL for all inspected externally painted surfaces is obtained by the intersection between the trend curve and the degradation severity of 20%. As shown in Fig. 2 and Table 5, the RSL obtained is 20.3 years. This result is higher than the RSL found in the literature; using the graphical method, Chai et al. [11] obtained an RSL value of 9.6 years with a paint coating number of 220 samples. Moreover, Magos et al. [4] deduced an RSL of 10.8 years; a variation of 10% compared to the value found by Chai et al. [11] is obtained with a larger number of facades (323 paint coatings). This result confirms that the number of samples studied has a significant effect on the determination of RSL by this graphical method. As a result, the second point of intersection between the two lines is due to the existence of outliers in the age interval of the coating between 35 and 40 years.

The analysis of the degradation curves of Sw values as a function of the coatings' age can also lead to the estimation of the SL of painted surfaces according to each studied characteristic (Table 5, Figs. 3,4). In this work, the Sw values of the two qualitative variables, namely the distance from the sea and the facade orientation, are considered for this analysis. Simple linear and nonlinear (polynomial) regression analysis was adjusted to different points of the graphs of the two studied variables, distance from the sea and facade orientation. The ESL of studied groups of paint coating samples with a specific independent variable is established through the intersection that occurred between each degradation curve and the severity level of 20% (Figs. 3,4).

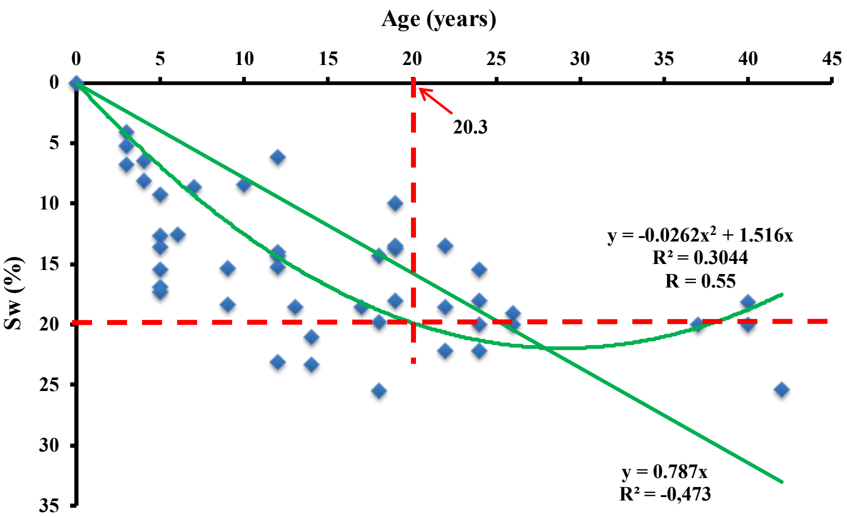


Fig. 2. *Estimation of the RSL of the investigated paint coating*

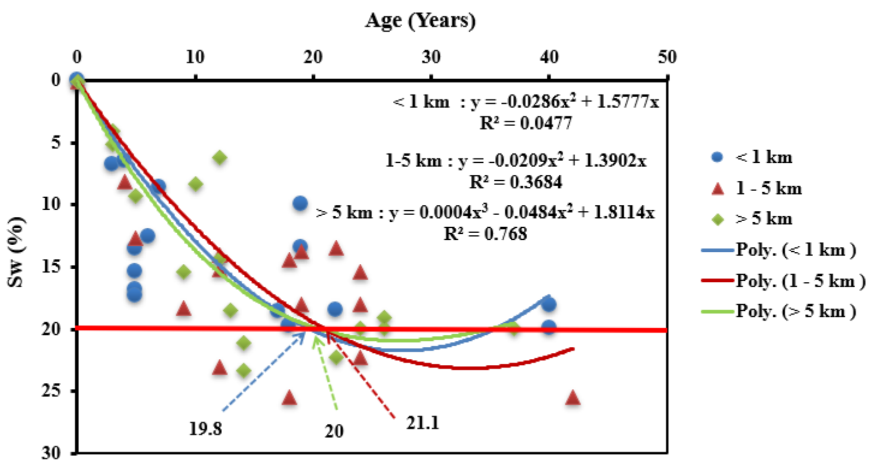


Fig. 3. *Severity index as a function of distance from the sea*

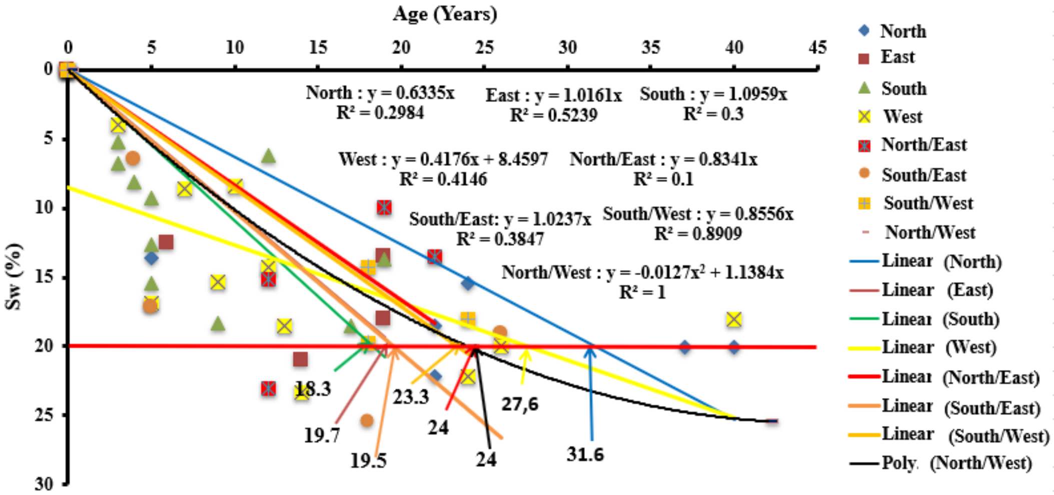


Fig. 4. *Severity index versus facade orientations*

The quantification of the qualitative variables is required before using the MLR analysis. In this study, each group of anomalies was expressed by the value that represents the ratio between the estimated service life (ESL) based on each coating characteristic and the RSL of 20.3 years (Table 5). The results shown in Table 5 indicate clearly that the distance from the sea significantly affects the SL of paint coatings. As a result of this, an ESL of 19.8 years was obtained for painted surfaces located within less than 1 km of the coastal zone. This estimation is less than 1.3 years compared to the facades located at distances from the sea more than 1 km, which is mainly due to the strong exposure of these paint surfaces to the high salinity of sea spray and humidity, which leads to the crystallization of salts at internal and external surfaces of studied coatings. This phenomenon mainly causes the formation of various damages at an early age, such as blisters, loss of adhesion, color change, biological colonization, etc. [17].

Moreover, Fig. 4 and Table 6 indicate that all facades oriented to the south, east, and south/east have a slightly lower SL compared to the other orientations. This result is mainly due to the high exposition of these facades to the solar radiation, which involves the development of different anomalies related to the sun exposure, such as color change, cracking, chalking, etc. However, this analysis indicates that the most favorable orientations regarding the durability of this type of coating for exterior facades of buildings in the Algiers region are north and west orientations. This result indicates the highest service life estimation of 31.6 and 27.6 years, respectively, for the north and west orientations.

Table 6. Quantification of qualitative independent variables

Characteristics	Independent variables	% of cases	RSL (years)	ESL (years)	Ratio between ESL and RSL	R^2 of degradation curves
Distance from the sea	< 1 km	33.33	20.3	19.8	0.975	0.0477
	1 – 5 km	33.33		21.1	1.039	0.3684
	> 5 km	33.33		20	0.985	0.768
Facade orientation	N	13.33		31.6	1.556	0.2984
	E	8.89		19.7	0.970	0.5239
	S	24.44		18.3	0.901	0.3
	W	24.44		27.6	1.359	0.4146
	N/E	8.89		24	1.182	0.1
	S/E	8.89		19.5	0.960	0.3847
	S/W	6.66		23.3	1.147	0.8909
	N/W	4.44		24	1.182	1

Mathematical model of Service life prediction

Regression analysis is one of the statistical techniques widely applied for studying the effect of one or several independent variables on the variation values of dependent variables, which are responsible for its performance. According to the results obtained by the two software programs, EXCEL and SPSS, the relationship between Sw values (variable Y) and the three considered independent variables, namely, coating age (CA), distance from the coastal zone (DS), and facade orientations (FO), is given in (6) and (7).

$$Y = -0.22 + 0.003\ (X_1) + 0.305\ (X_2) + 0.021\ (X_3). \quad (6)$$

$$S_w = -0.22 + 0.003\ (CA) + 0.305\ (DS) + 0.021\ (DO). \quad (7)$$

It should be noted from both (3) and (4) that the value of each coefficient translates the importance of the adequate independent variables in the prediction of dependent variable values. Indeed, the coefficient of the coating age variable is positive in the model; as a result, the degradation severity increases significantly with increasing its values. In the case of the other variables, distance from the sea and the facades' orientations, their coefficients are also positive but with a low effect on the variability of Sw values; a variation around 0.5 is estimated.

On the other hand, in the case of each coating sample and for a Sw level of 20%, the estimation of service life can be obtained using (8), where the coating age is considered as the dependent variable.

$$\text{ESL} = \frac{(0.2 + 0.22 - 0.305\ (DS) - 0.021(FO))}{0.003}. \quad (8)$$

Based on the quantification results of independent variables (shown in Table 6), the age of paint surfaces can be estimated for a 20% degradation severity. The ESL is deduced using (8); therefore, the average of all ESL values is calculated for each observation. In addition, the standard deviation of the RSL can also be determined by this method. As a result, the ESL is around 29.9 ± 3.26 years. This estimation is obtained based on degradation severity data in the range of 4-25%, and the age of the coating is between 3 to 40 years. Figures 5 and 6 translate the correlation between the experimental and the estimated values of the severity index Sw. Fig. 6 indicates that a high correlation is obtained between predicted values calculated using (4).

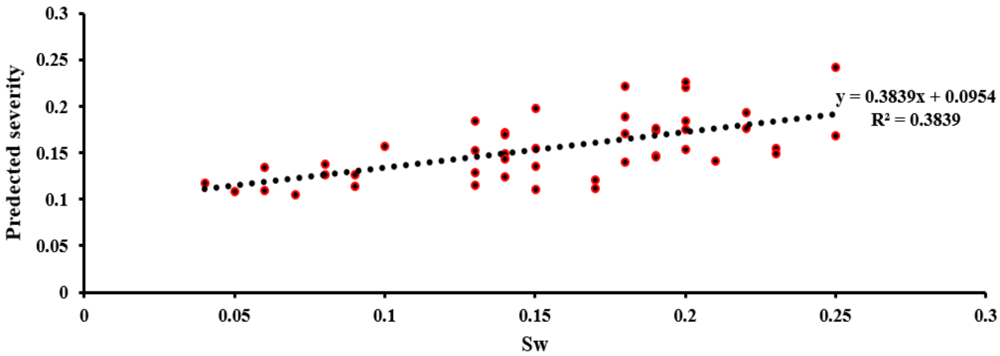


Fig. 5. *Correlation between predicted and experimental severity index*

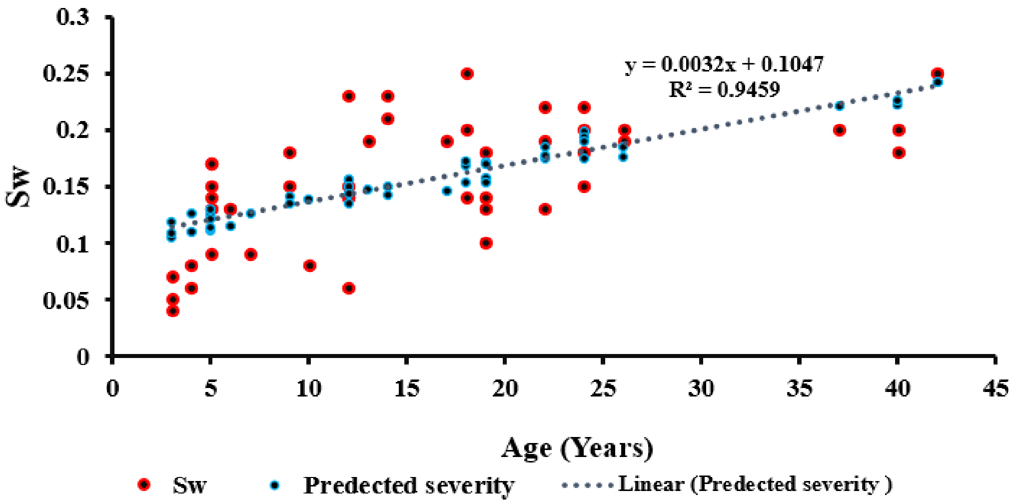


Fig. 6. *Experimental and predicted values of Sw as a function of coating age*

Performance testing of model

The prediction of the SL of six painted surfaces applied to the external walls of selected Algiers building envelopes is investigated for the evaluation of the performance of the SL prediction of the mathematical model obtained via the MLR analysis (Table 7). The statistical investigation for studying the validation of the statistical performance of the mathematical model obtained in this work is conducted by Hammas et al. [18]. As a result, the ESL deduced from the proposed model in this study for all inspected painted surfaces is in accordance with the real ages declared by OPGI. This reflects the good performance of this model in the intervals of coating age and degradation severity studied, 3-40 years and 4-25%, respectively. An example of the calculation method of Sw is indicated in (9) for the LBB 3 coating sample. In addition, the results illustrated in Table 7 also indicate that the prediction of the age of the coating strongly depends on the distance from the sea and the orientation of the facade. An increase in the predicted age from 8.03 to 13.4 years is noted for the two facades, LBB 2 and LBB 3, facing north and east, respectively, which have the same distance from the sea and the same age. This result is in agreement with the conclusions obtained by the graphical study used for the quantification of qualitative independent variables.

$$S_w = \frac{\sum(A_n \cdot k_n \cdot k_{a,n})}{At \cdot k} \cdot 100 =$$

$$= \frac{(A_{CC} \cdot k_{CC} \cdot k_{a,n(CC)}) + (A_{CG} \cdot k_{CG} \cdot k_{a,n(CG)}) + (A_{CK} \cdot k_{CK} \cdot k_{a,n(CK)}) + (A_B \cdot k_B \cdot k_{a,n(B)}) + (A_P . k_P \cdot k_{a,n(P)})}{At * k} \cdot 100 = \quad (9)$$

$$= \frac{(107.05 \cdot 1 \cdot 0.55) + (107.05 \cdot 2 \cdot 0.6) + (0.015 \cdot 2 \cdot 1) + (107.05 \cdot 2 \cdot 0{,}8) + (8.02 \cdot 3 \cdot 0.8)}{267.62 \cdot 10} \cdot 100 = 14.12\ \%.$$

Table 7. Comparative study between the performance service life prediction obtained using the mathematical model obtained in this work and Chai et al. [11]

Paint coating samples	Distance from the sea	Facade orientations	Sw (%)	Real age (ans)	Service life prediction $\pm$ 3.26 ans [a]	Service life prediction $\pm$ 0.54 ans [b]
CRAH	< 1 km	Sud/Est	22.193	**43**	**41.46**	**x**
CFEM	1-5 km	Sud/Est	12.79	**5**	**3**	**x**
CLEM		Est	12.961		**4.11**	**7.29**
LBB 1	> 5 km	Ouest	13.846	**10**	**9.85**	**7.20**
LBB 2		Nord	13.722		**8.03**	**8.14**
LBB 3		Est	14.121		**13.4**	**8.16**

x: Orientation facades were not considered by the investigation work of Chai et al. [11].
[a] Coating age predicted using the mathematical model obtained in this study.
[b] Coating age predicted using the mathematical model obtained by Chai et al. [11].
Green color: The SL prediction is near the real age of the inspected paint coating.
Red color: The SL prediction is far from the real age of the inspected paint coating.

On the other hand, a comparative study is established between the performance of service life prediction calculated using the mathematical model obtained in this work and the model proposed by Chai et al. [11]. Table 7 indicates clearly that the statistical model obtained during this study gives a better precision than the literature model established by Chai et al. [11] for some paint coatings of building envelopes. Moreover, it can be noted that the MLR model developed by Chai et al. [11] has a certain limit for the prediction of aged coatings higher than 30 years. Over this limit of age, the values of Sw are equal to 100%. In contrast, the statistical model obtained during this work can be used for the estimation of the SL of paint coatings aged for more than 30 years, as indicated in the case of the paint coating of the CRAH building facade. The comparison between the performance of both developed MLR models concluded that the obtained model during this study gives good precision despite the moderate quantity of investigated paint coating (45 building facades). To emphasize that performance, the values of the service life predictions close to the real age of the paint surfaces are colored in green in Table 7.

In order to elaborate on the relationship between the detected degradation and the calculated Sw values, different presentations of images are presented with mapping of detected anomalies that were observed at different investigated surfaces of paint applied to the external walls. The three anomalies are mapped, namely color change, cracking, and loss of adherence (Fig.7). The alignment of the different images with their maps was carried out using the two software programs Photoshop and Paint.

It can be seen that the three considered factors have a significant effect on the degradation severity, namely, the coating age, the distance from the sea, and the facades' orientations. Moreover, according to the degradation mapping illustrated in Fig.7, the formation of loss of adhesion (peeling) and color change on the painted surfaces of the exterior facades of buildings is strongly related to the orientation of the buildings. Indeed, more intense peeling degradation is detectable on the painted surface of LBB 3 facades that are 10 year old, facing east and present a degradation severity of 14.121% (Fig.7f). This result is in agreement with the prediction results obtained for the coating age of the different degradation severity which increase on the facades oriented to the East, South, and South/East.

(a)

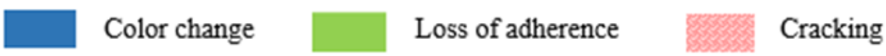
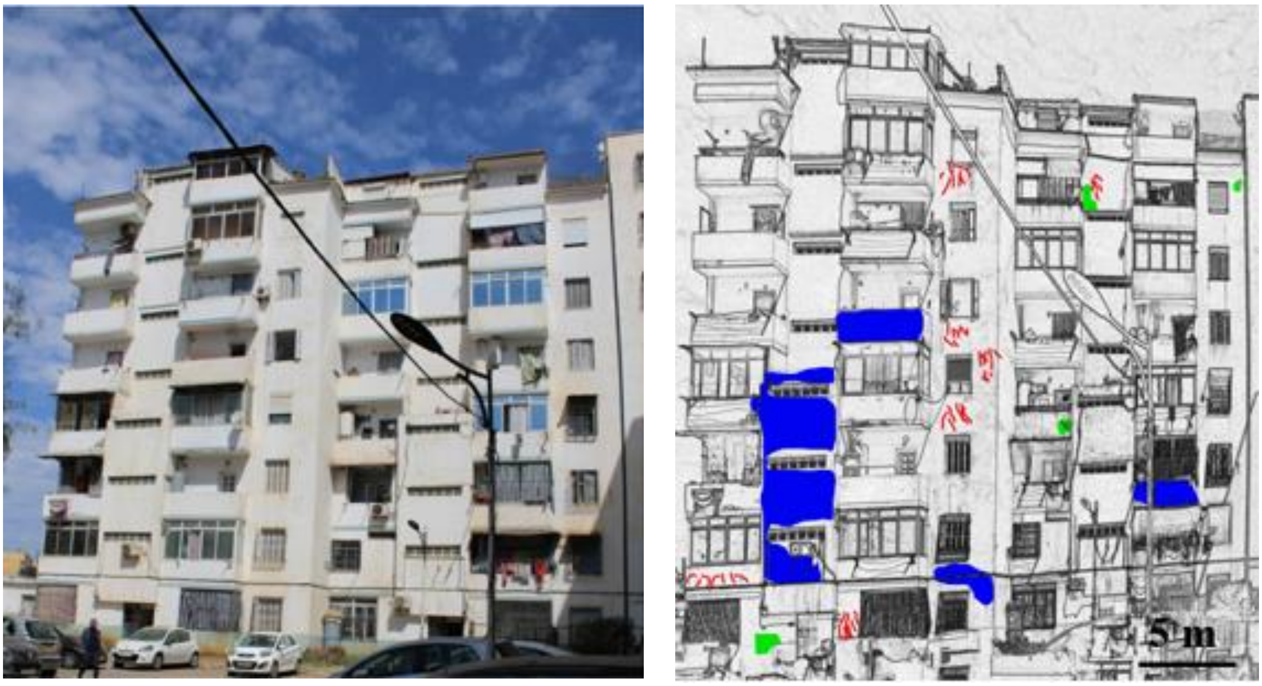


Fig. 7. *Mapping of detected anomalies at different inspected surfaces paints:*
(a) *CRAH,* (b) *CFEM,* (c) *CLEM,* (d) *LBB 1,* (e) *LBB 2,* (f) *LBB 3*

Fig. 7 (continued)



(b)

Color change Loss of adherence Cracking

(c)

Color change Loss of adherence Cracking

Fig. 7 (continued)

(d)

Color change   Loss of adherence   Cracking

(e)

Color change   Loss of adherence   Cracking

Fig. 7 (continued)

(f)

Color change Loss of adherence Cracking

Conclusion

In this work, the prediction of the SL of external wall paintings is established using regression analysis based on linear and multilinear regression. A statistical method is used to analyze 45 painted surfaces of external walls of residential buildings located in Algiers. The methodology to assess the SL of coatings is based principally on the visual evaluation of different forms of degradation. The visual evaluation is treated to extract quantification data, and the results are translated into a mathematical model. The combination of the data collected with the anomalies detected in in-service conditions was expressed as numerical values using the graphical method. In addition, the mathematical model is established in this study by relating the degradation severity and the three independent variables, namely, the coating age, the distance from the coastal zone, and the solar orientation facade. According to the results obtained during this study, the following conclusions can be drawn:

- RSL of 20.3 years of studied coating is obtained using the simple linear regression analysis (graphical method).
- Based on the parameters of the model, the SL of paint coating applied to the external wall of the Algiers building depends strongly on the distance from the sea and facade orientations. The lowest ESL of 19.8 years was obtained for an external facade building situated near the coastal zone, and for facades facing east, south, and east/south, 19.7, 18.3, and 19.5 years, respectively.
- For 20% of degradation severity, the ESL of 29.9 ± 3.26 years is obtained from the average of all ESL for investigated paint surfaces, which presents a degradation severity and coating age between 4 and 25% and 3 and 40 years, respectively. It appears that the ESL is consistent with empirical data related to the durability of paint coating, which can also be deduced via this model, even for values beyond 25% in terms of overall deterioration of the considered coating, which is not the case on the models consulted in the literature.
- The comparison study between the MLR model obtained during this work and the developed model in the previous investigations about the ESL of paint coating concluded that a good precision has been attained on the estimation of the SL of six other paint surfaces, which present deterioration severities in the range of 4 and 25%.

Conflict of Interest

The authors declare no conflicts of interest.

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